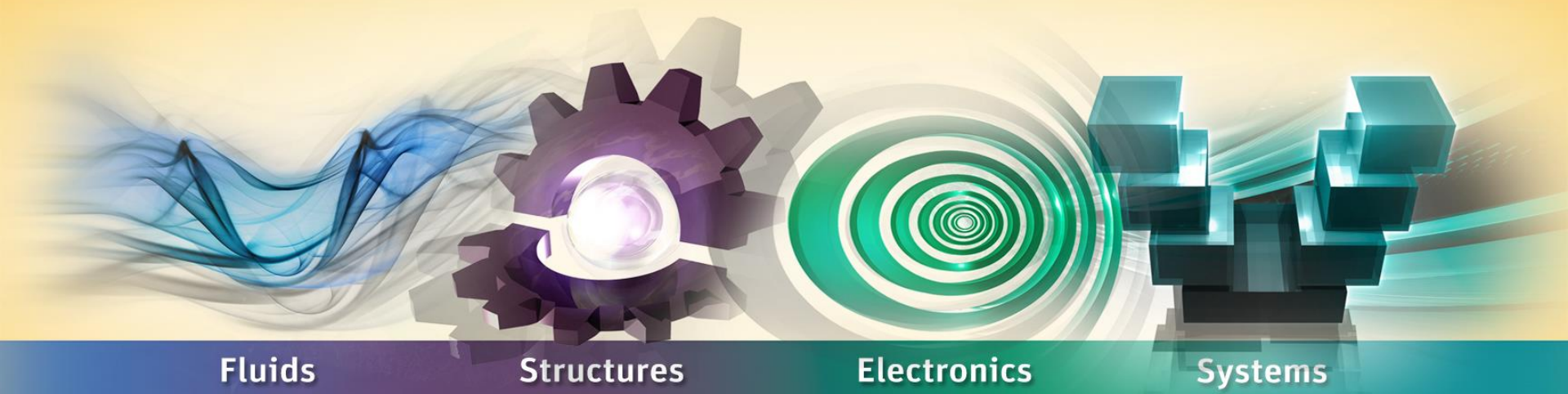
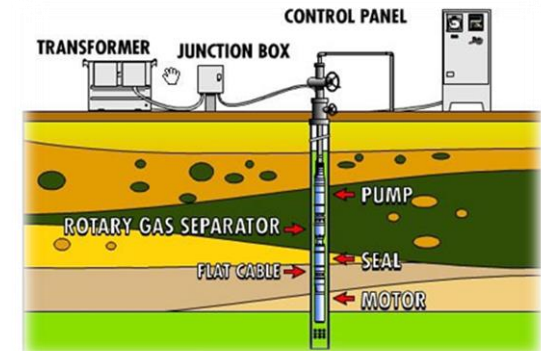
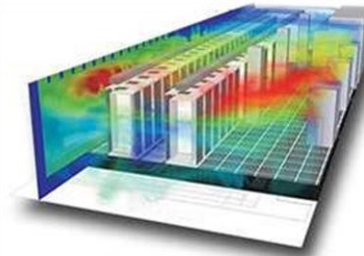
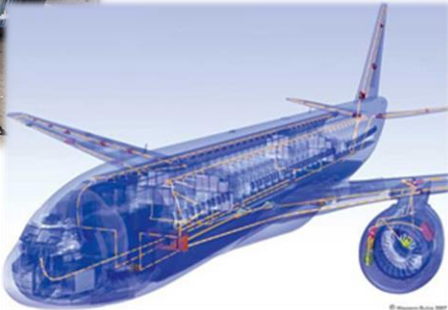
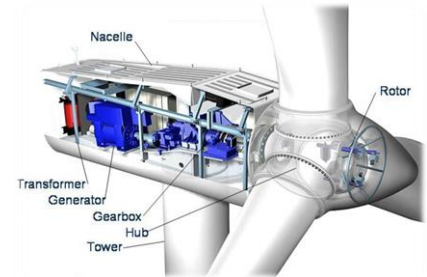


# Virtual System Prototyping

*Modeling & Simulation with Simplorer*



# Electrified Systems – They're Everywhere



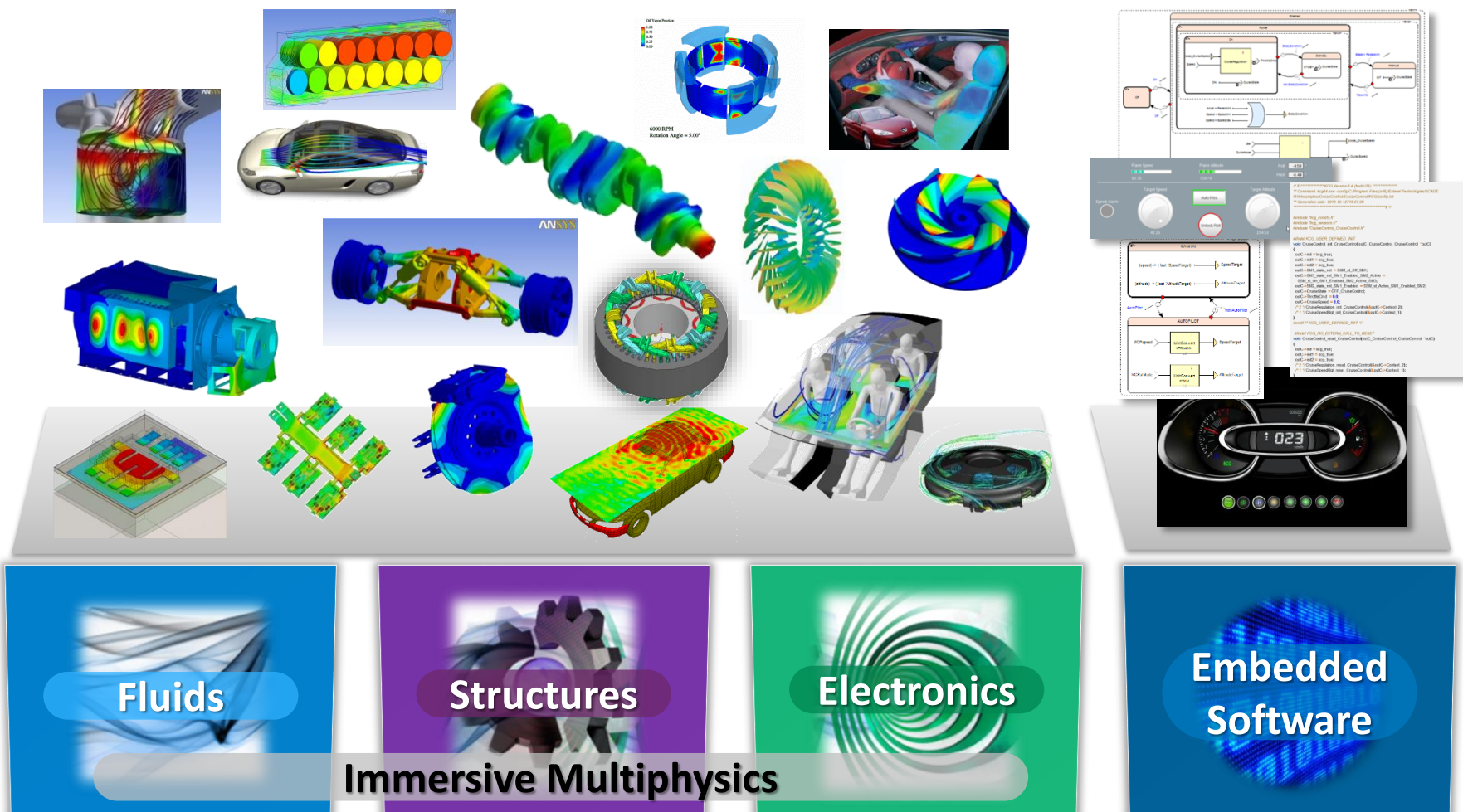
It's an opportunity to innovate...

- Powering, Actuating, Sensing, Controlling products in new ways

...with a lot at stake

- Better performance
- Higher efficiency
- Lower cost
- Higher reliability

# Comprehensive Component-Level Design



Fluids

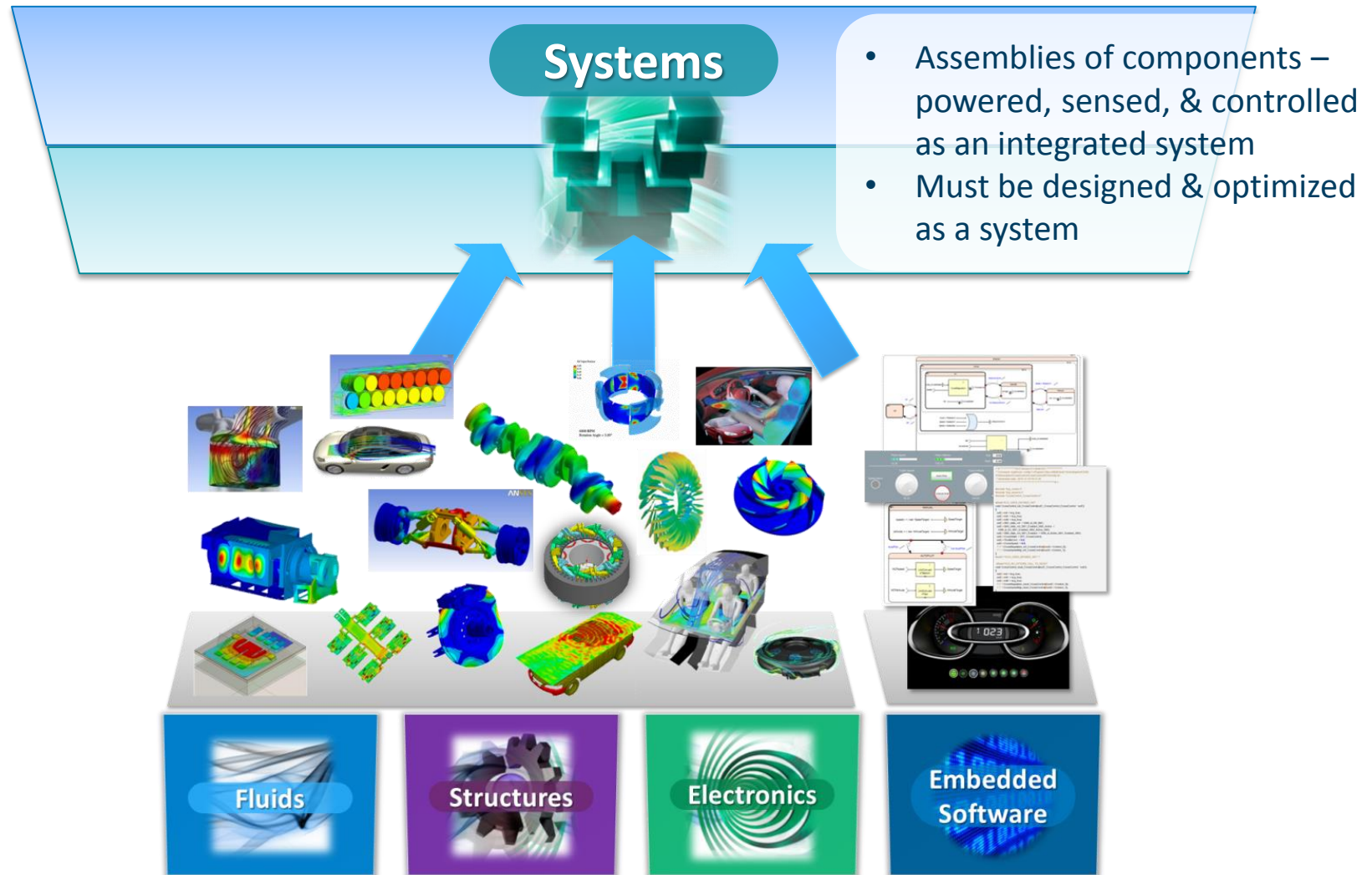
Structures

Electronics

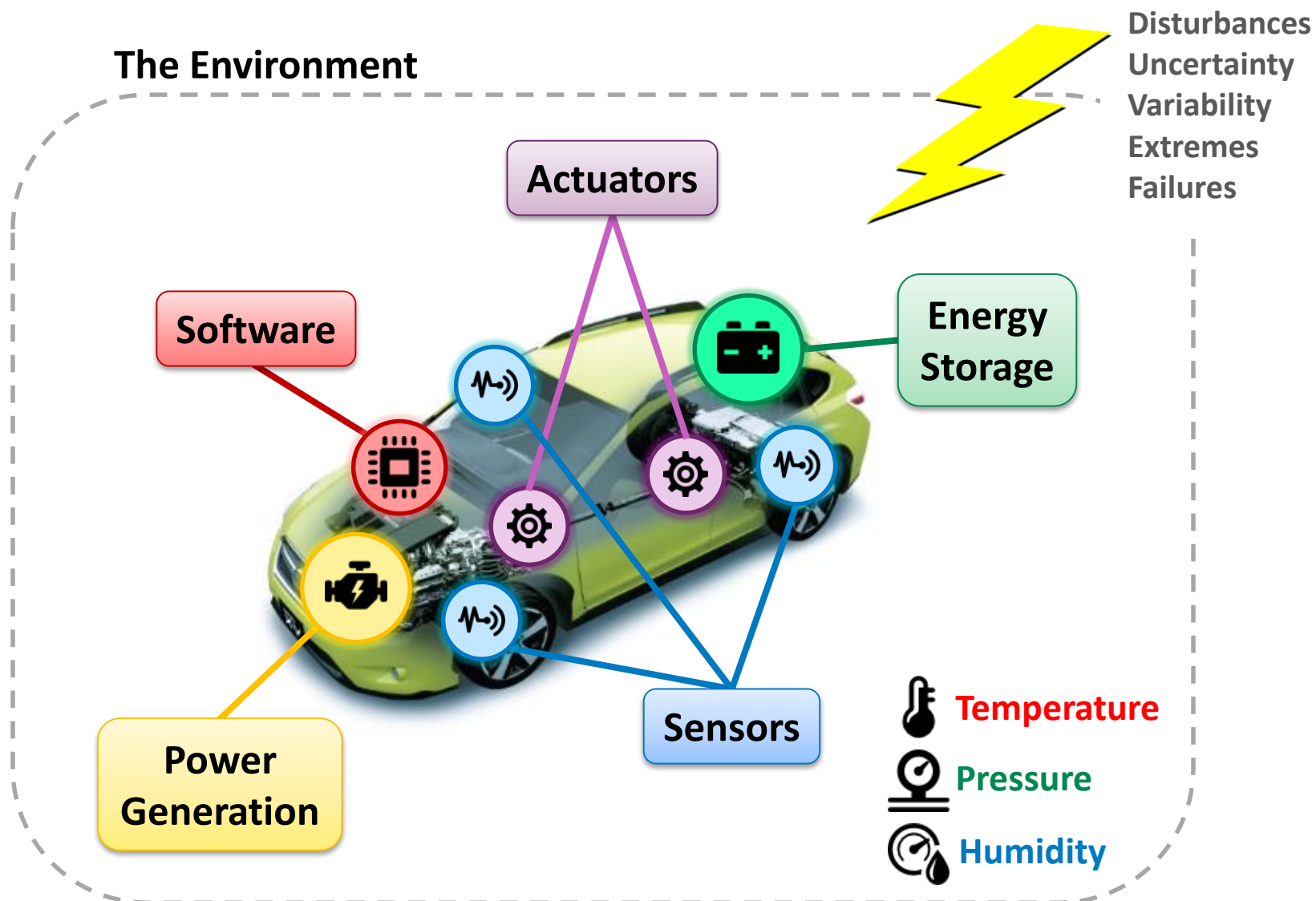
Embedded  
Software

Immersive Multiphysics

# The Next Level: Systems



# What is a System?



# Why is System Simulation Useful?

## *At the start of the design process*

- Early Architectural Tradeoffs
- “Simulation-in-the-loop” for predictive studies
- Pre-Sales / Collaboration tool

## *During the design process*

- Embedded Control Algorithm Design / Tuning
- System Verification / Validation
- Virtual Integration

## *At the end of the design process*

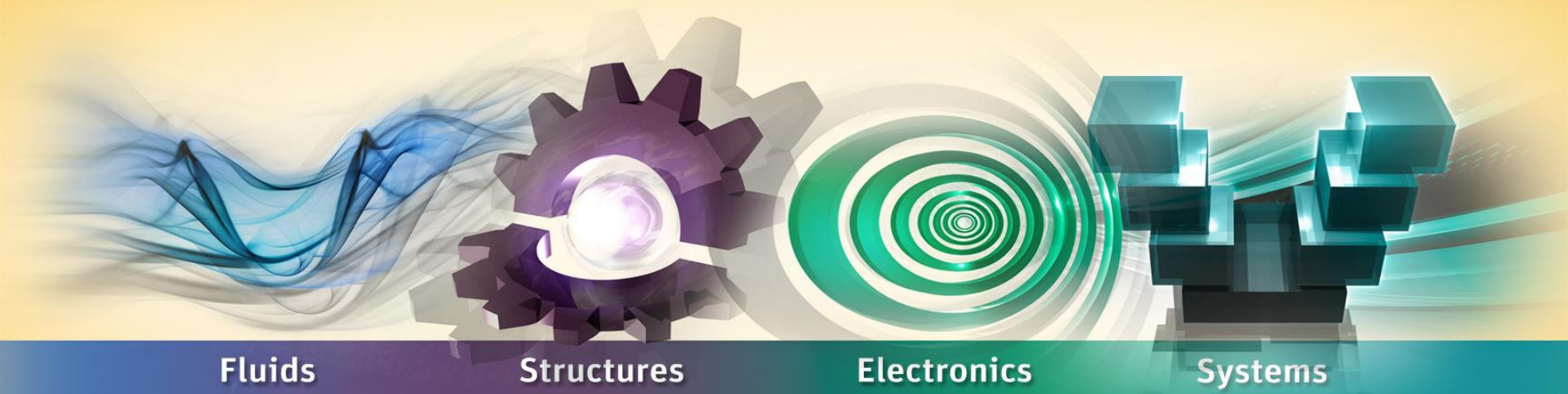
- System Performance Optimization
- Robust Design

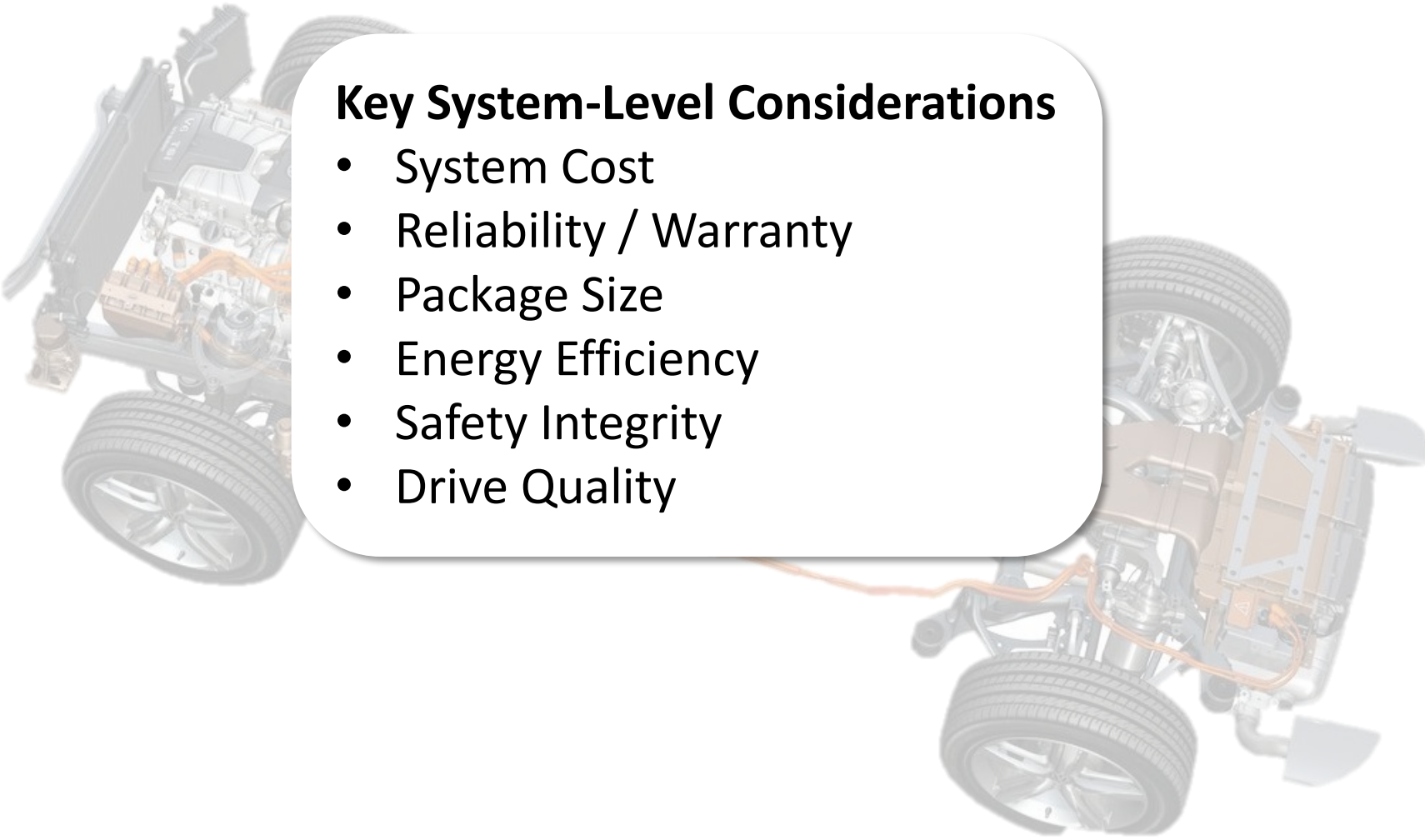
## *After the design process has been completed*

- Predictive Maintenance
- Adaptive Controls Tuning

# A System Example

## *Electric Vehicle Drivetrain*



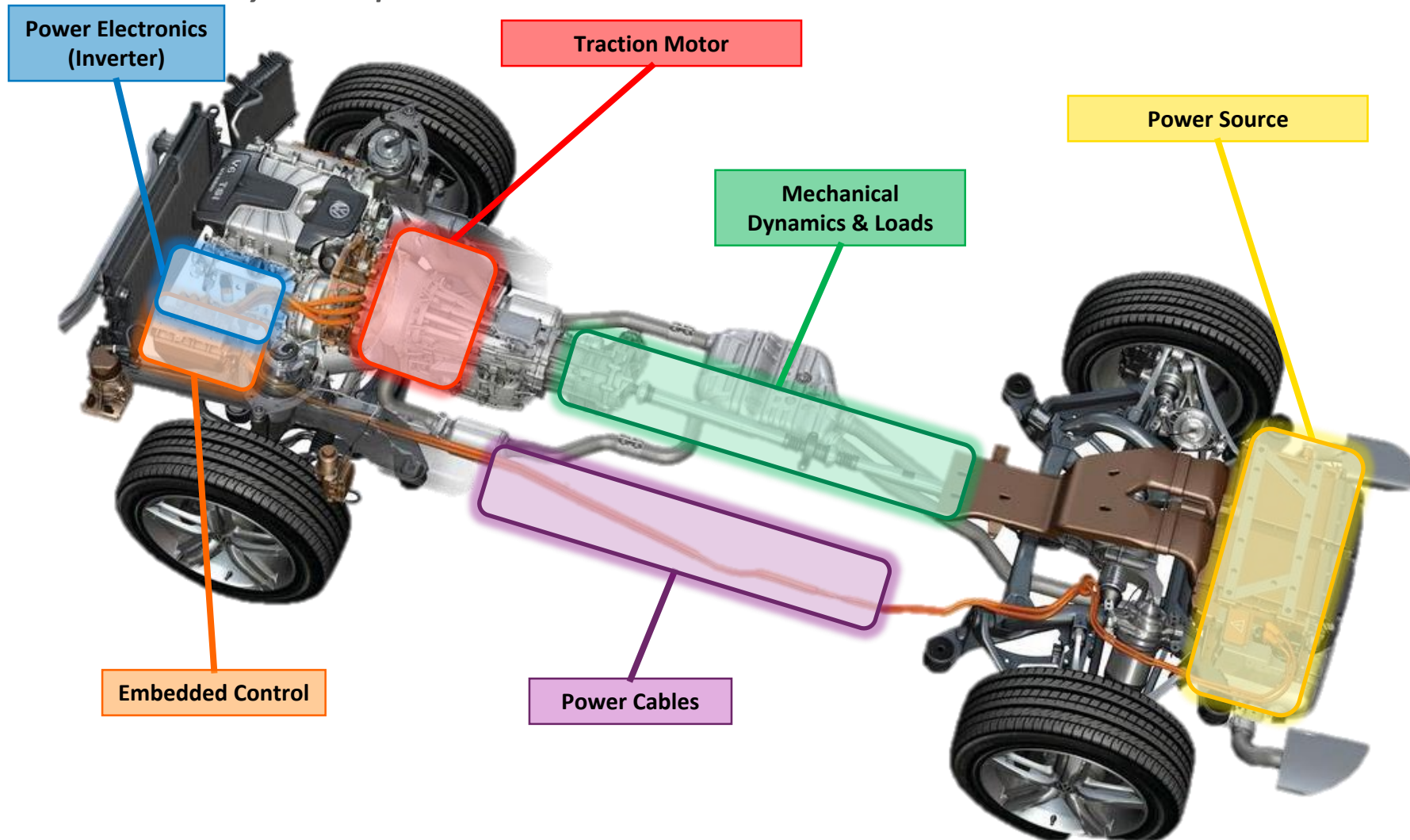


## Key System-Level Considerations

- System Cost
- Reliability / Warranty
- Package Size
- Energy Efficiency
- Safety Integrity
- Drive Quality

# Electric Vehicle Drivetrain

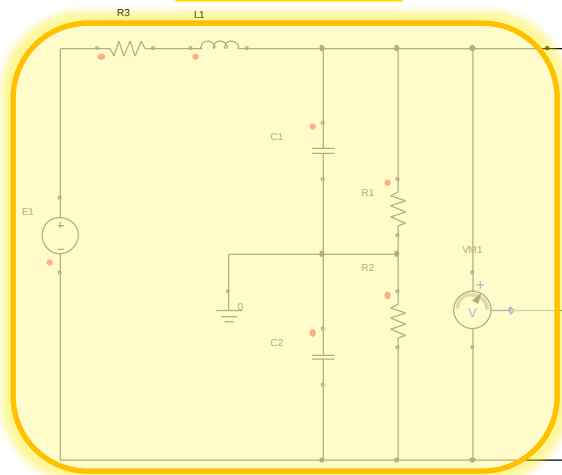
## *Key Components*



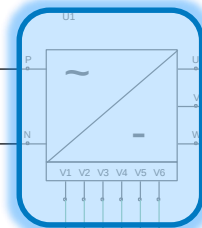
# Electric Vehicle Drivetrain

## *As a System Model*

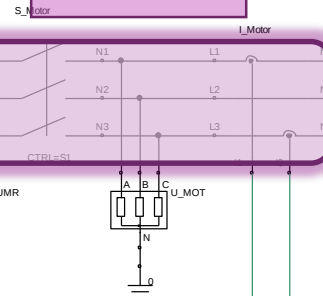
### Power Source



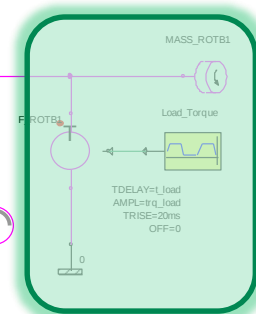
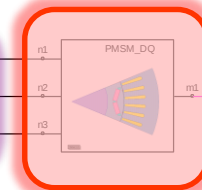
### Power Electronics: Inverter



### Power Cables

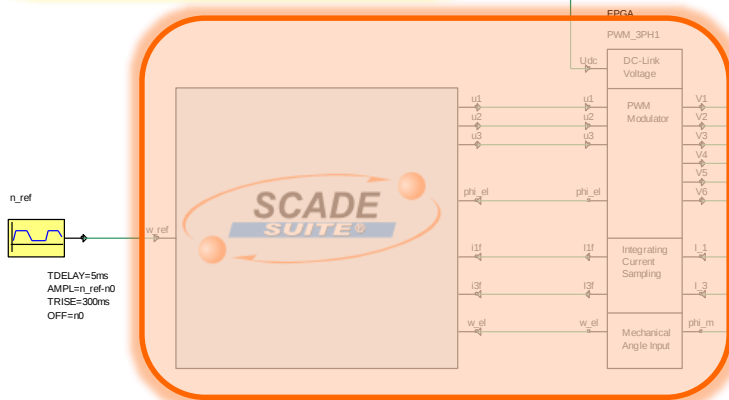


### Traction Motor (PMSM)



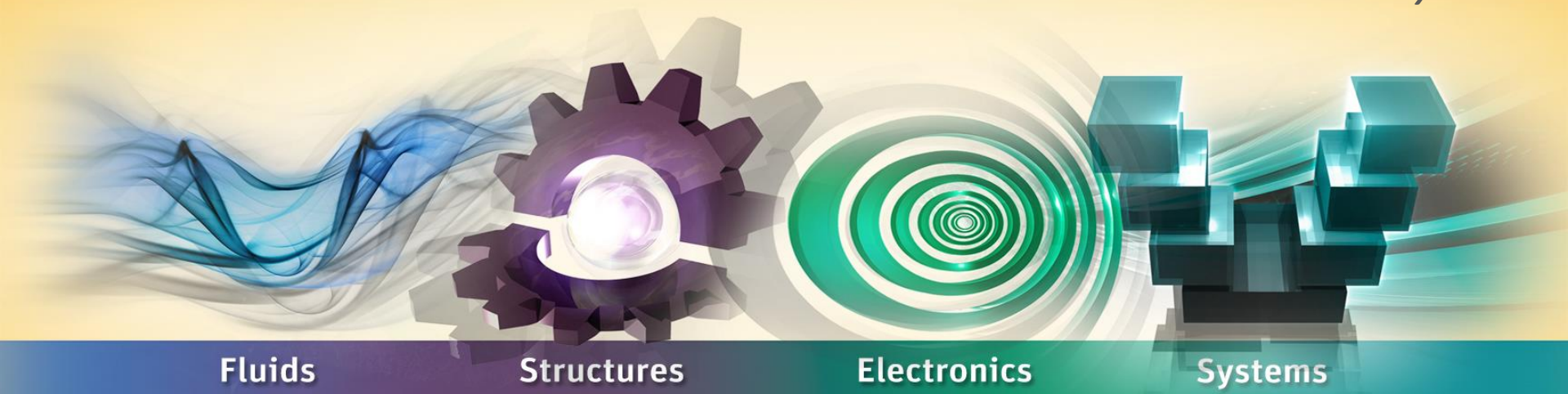
### Mechanical Dynamics & Loads

### Embedded Control



# System Modeling

*Detail & Fidelity*



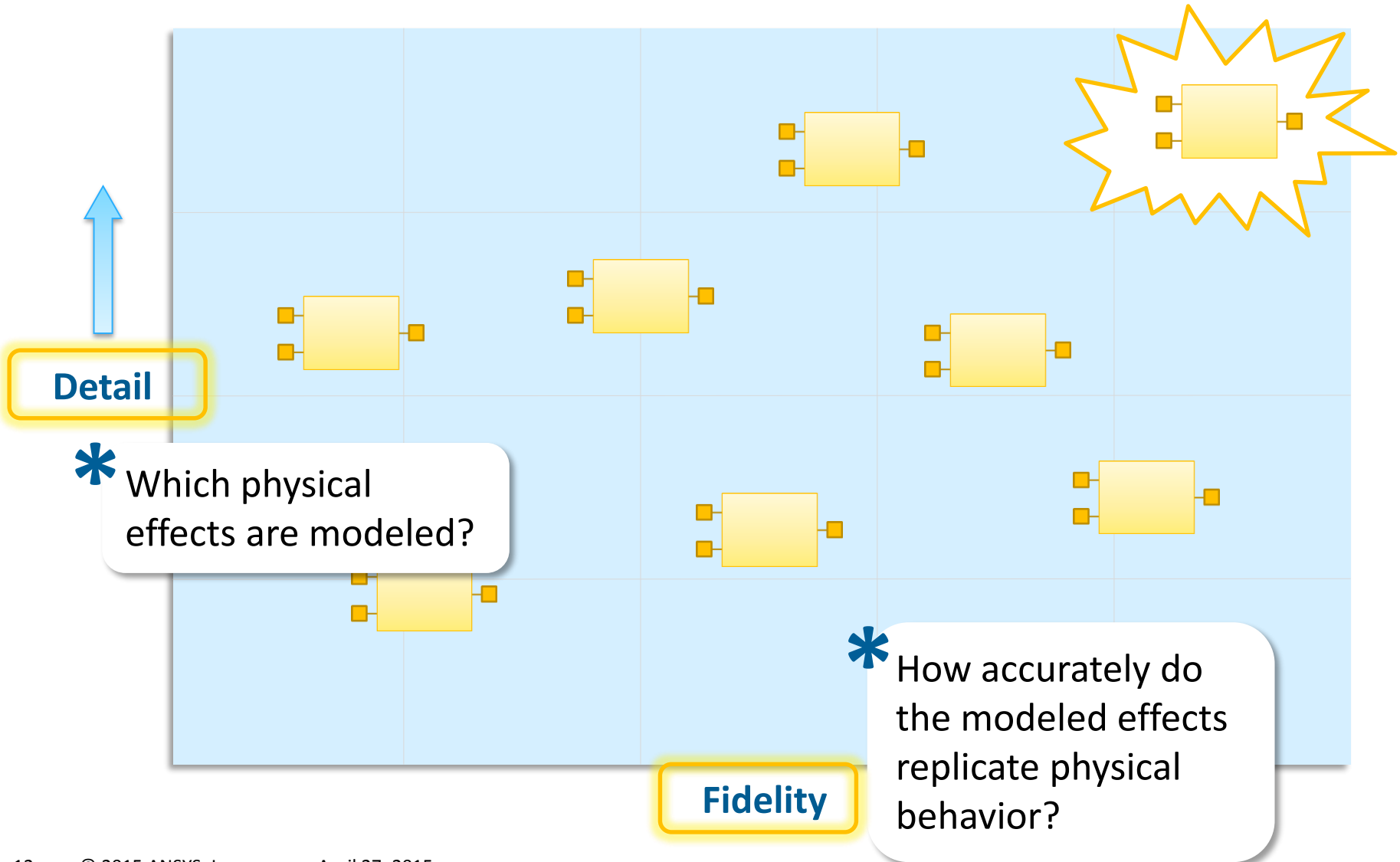
Fluids

Structures

Electronics

Systems

# Model Detail & Fidelity

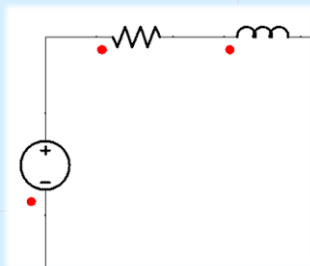


# Modeling the EV System

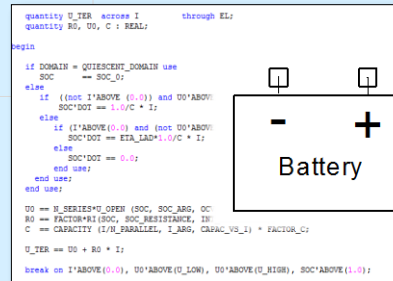
## Power Source



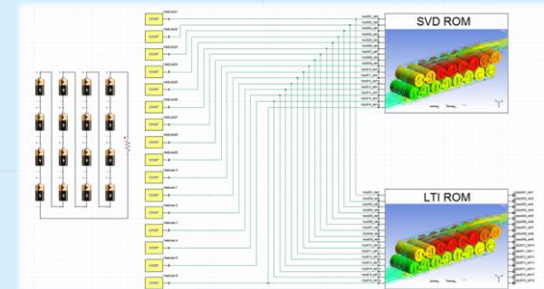
Detail



Basic Equivalent Circuit



VHDL-AMS  
Behavioral Model

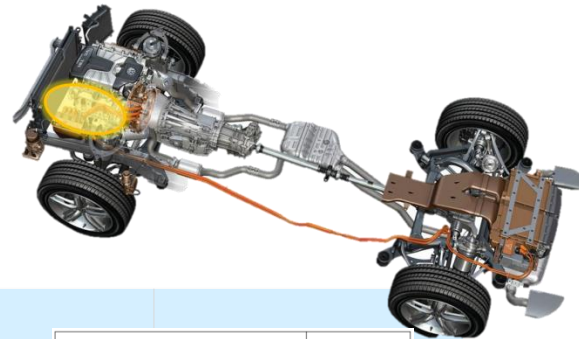


Equivalent Circuit Model  
+ CFD ROM

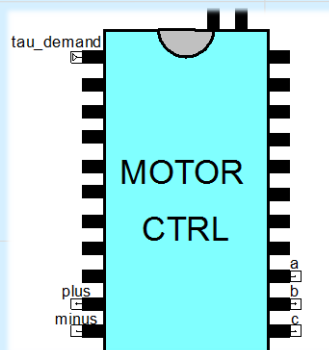
Fidelity

# Modeling the EV System

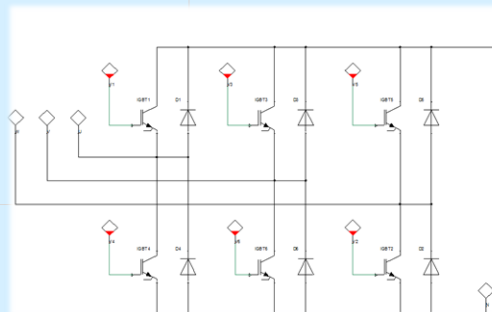
## Power Electronics: Inverter



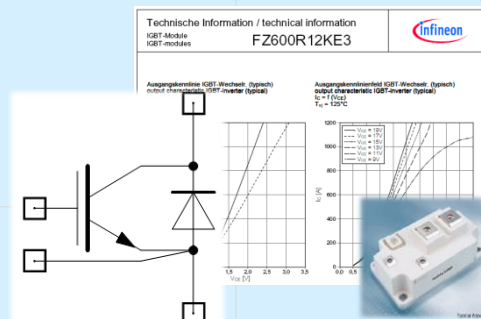
Detail



State-Averaged  
Controller



3-phase Inverter with  
Ideal IGBTs



3-phase Inverter with  
Dynamic Thermal IGBTs

Fidelity

# Modeling the EV System

## Traction Motor



Detail

```
-- electrical and mechanical angle relation
phi_e == p_real/2.0 * phi_m;
omega_e == p_real/2.0 * omega_m;

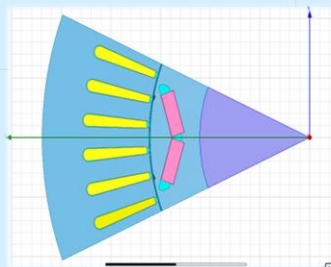
-- Park's Transformation
v_a == cos(phi_e) * v_d - sin(phi_e) * v_q + v_0;
v_b == cos(phi_e - two_third_pi) * v_d - sin(phi_e - two_third_pi) * v_q + v_0;
v_c == cos(phi_e + two_third_pi) * v_d - sin(phi_e + two_third_pi) * v_q + v_0;

i_a == cos(phi_e) * i_d - sin(phi_e) * i_q + i_0;
i_b == cos(phi_e - two_third_pi) * i_d - sin(phi_e - two_third_pi) * i_q + i_0;
i_c == cos(phi_e + two_third_pi) * i_d - sin(phi_e + two_third_pi) * i_q + i_0;

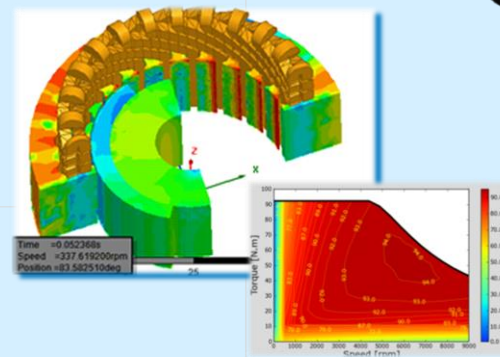
-- angular speed
if domain == 'mech' then
  phi_m' == omega_m;
else
  phi_m' == omega_e;
end use;

-- dynamic equations
l_d * i_d' == v_d - r_s * i_d + omega_e * l_q * i_q;
l_q * i_q' == v_q - r_s * i_q - omega_e * l_d * i_d;
l_0 * i_0' == v_0 - r_s * i_0;
```

**VHDL-AMS  
Behavioral Model**



**Electric Circuit  
Equivalent ROM**



**Co-simulation  
with 2D/3D FEM**

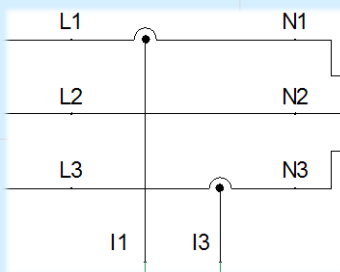
Fidelity

# Modeling the EV System

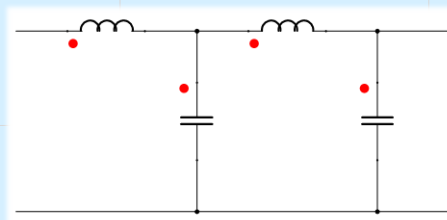
## Power Cables



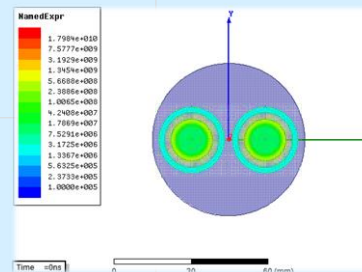
**Detail**



**Ideal Connections**



**Lumped Element  
Lossless Model**

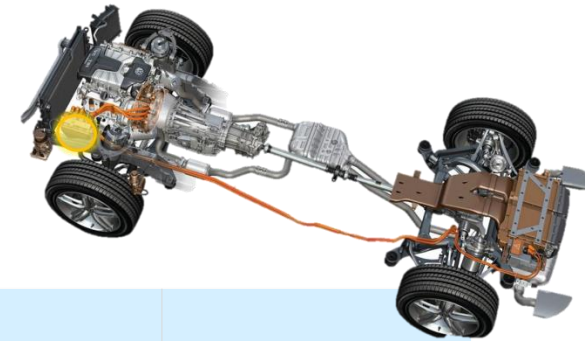


**S-Parameter ROM  
for Distributed Tx Lines**

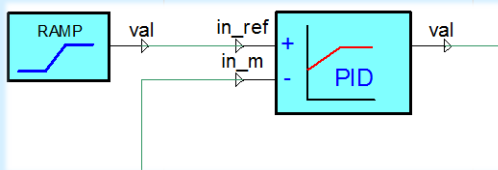
**Fidelity**

# Modeling the EV System

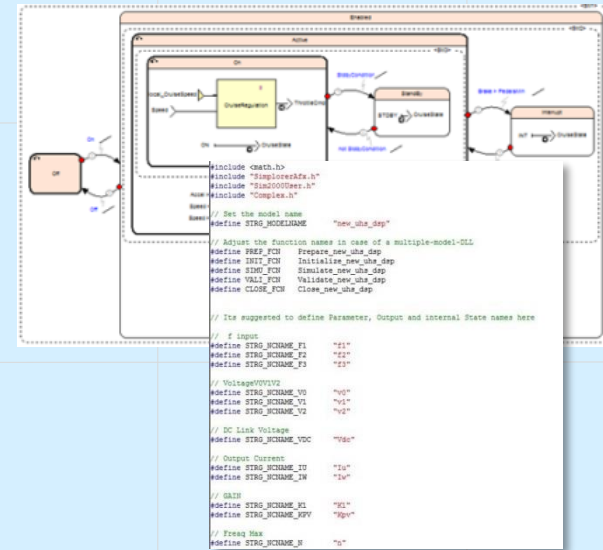
## *Embedded Control*



Detail



Ideal Control Blocks

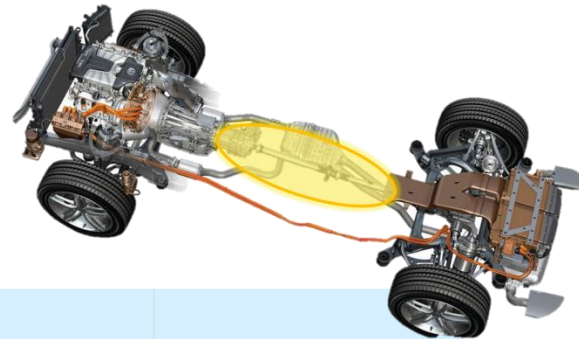


Generated Control  
Application Code

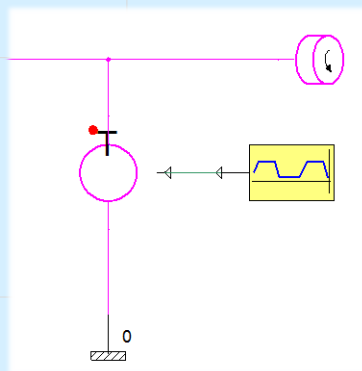
Fidelity

# Modeling the EV System

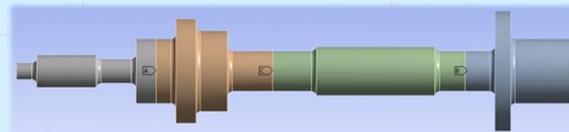
*Mechanical Dynamics*



↑  
**Detail**



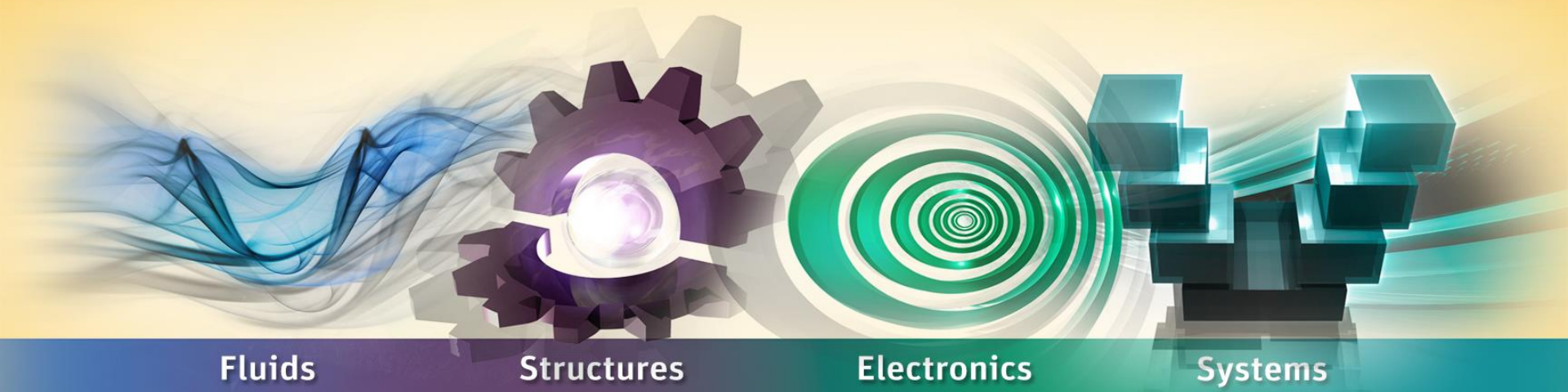
**Lumped Element  
Mechanical Effects**



**Mechanical ROM of  
Flexible Shaft**

**Fidelity** →

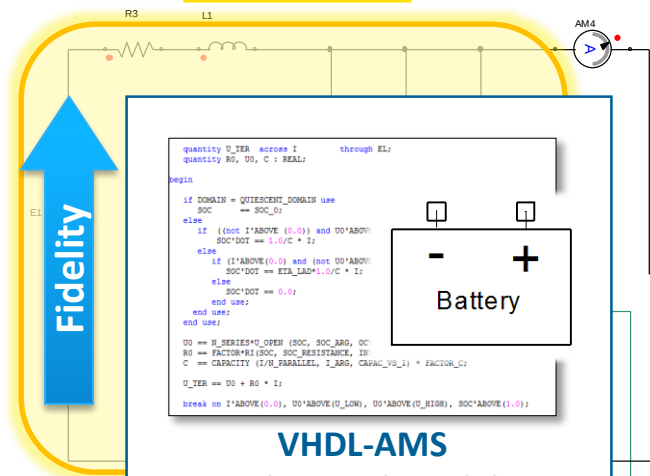
# System Assembly & Analysis



# Assembling & Analyzing the System

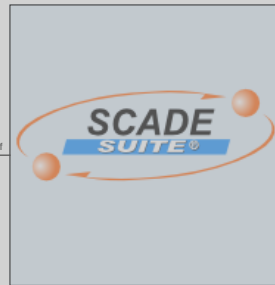
*Goal: Evaluate System Architecture, Size Key Components*

## Power Source

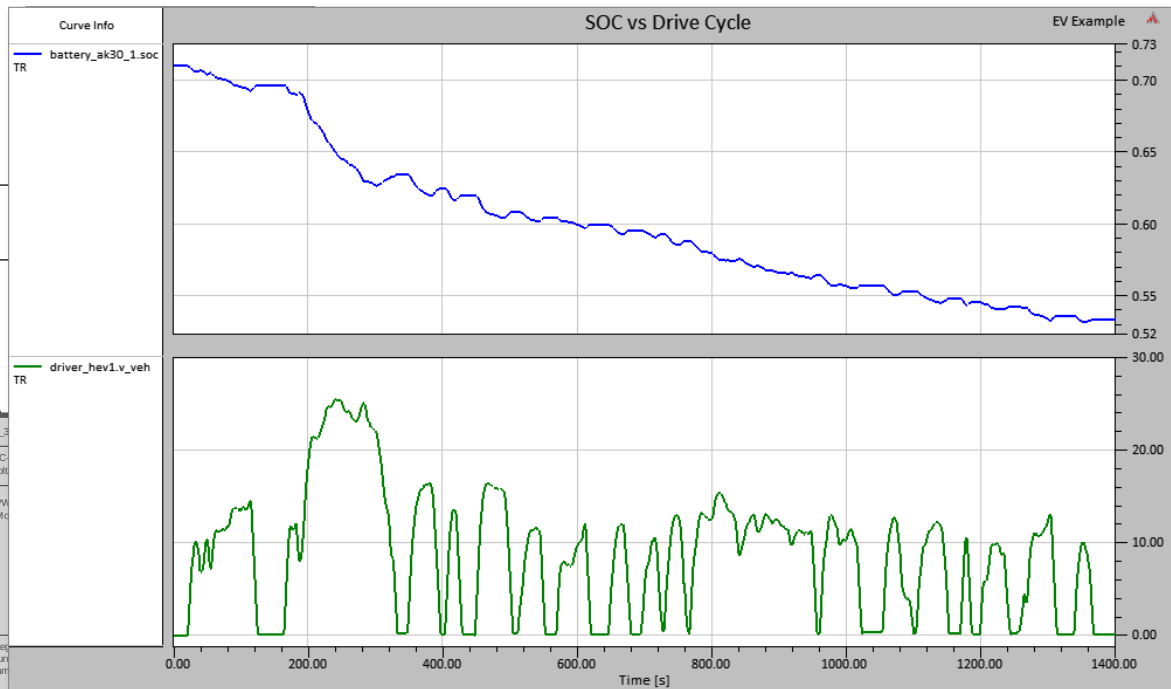


## VHDL-AMS Behavioral Model

n\_ref  
TDELAY=5ms  
AMPL=n\_ref\*r0  
TRISE=300ms  
OFF=r0

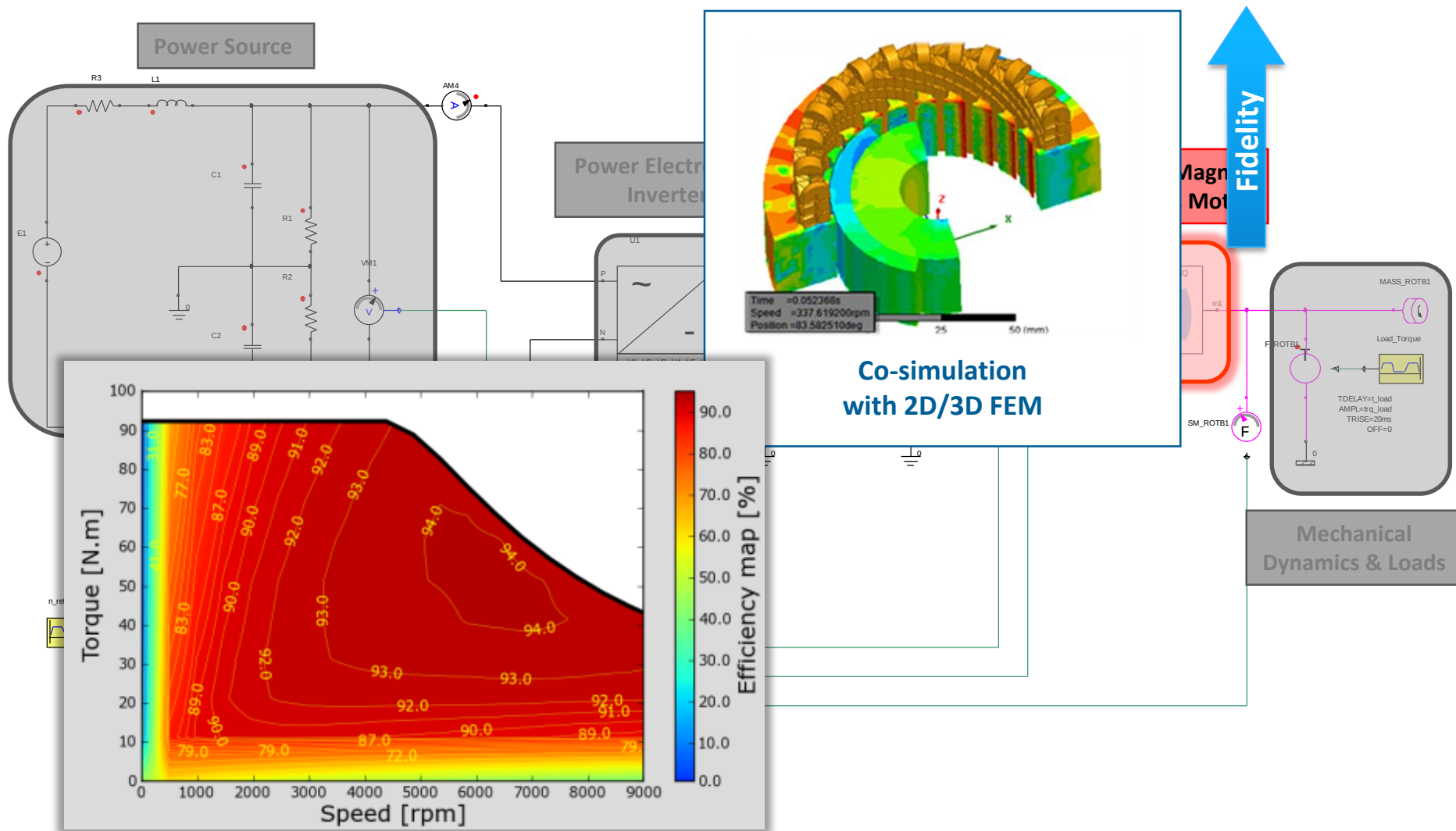


## Embedded Control

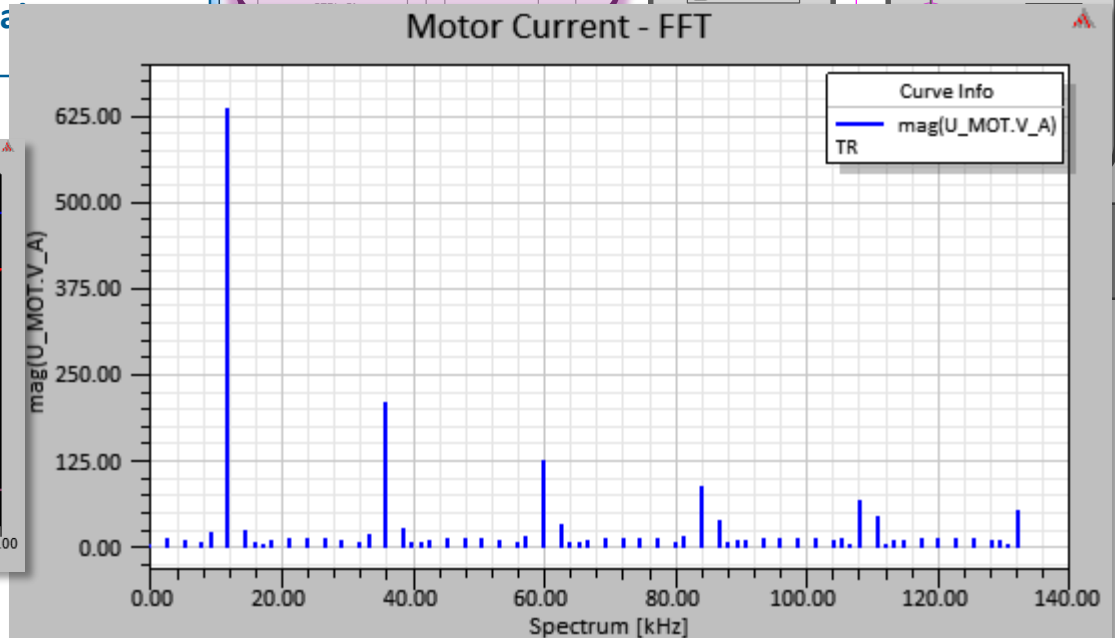
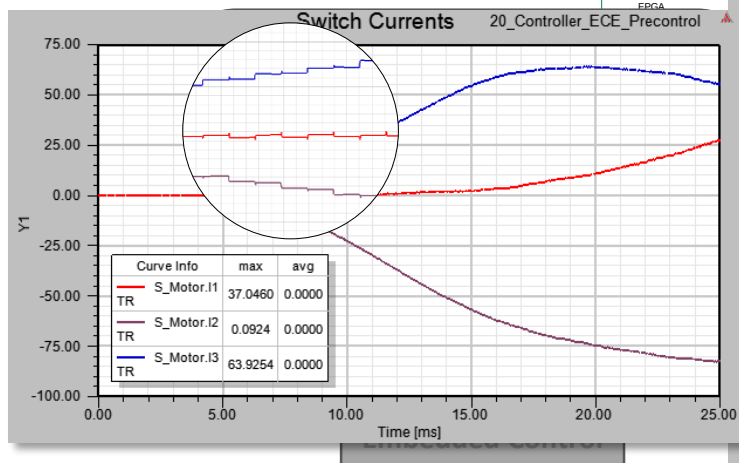
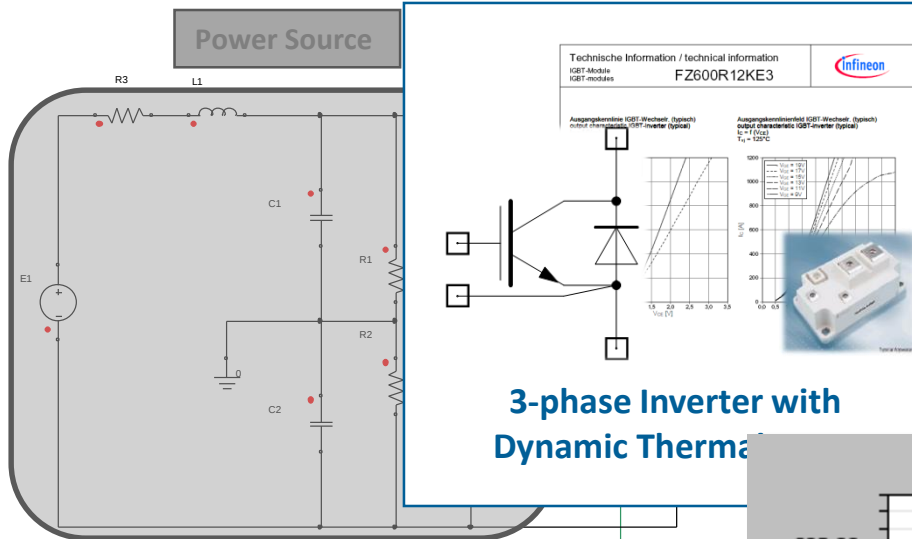


# Assembling & Analyzing the System

*Goal: Characterize Motor Losses*

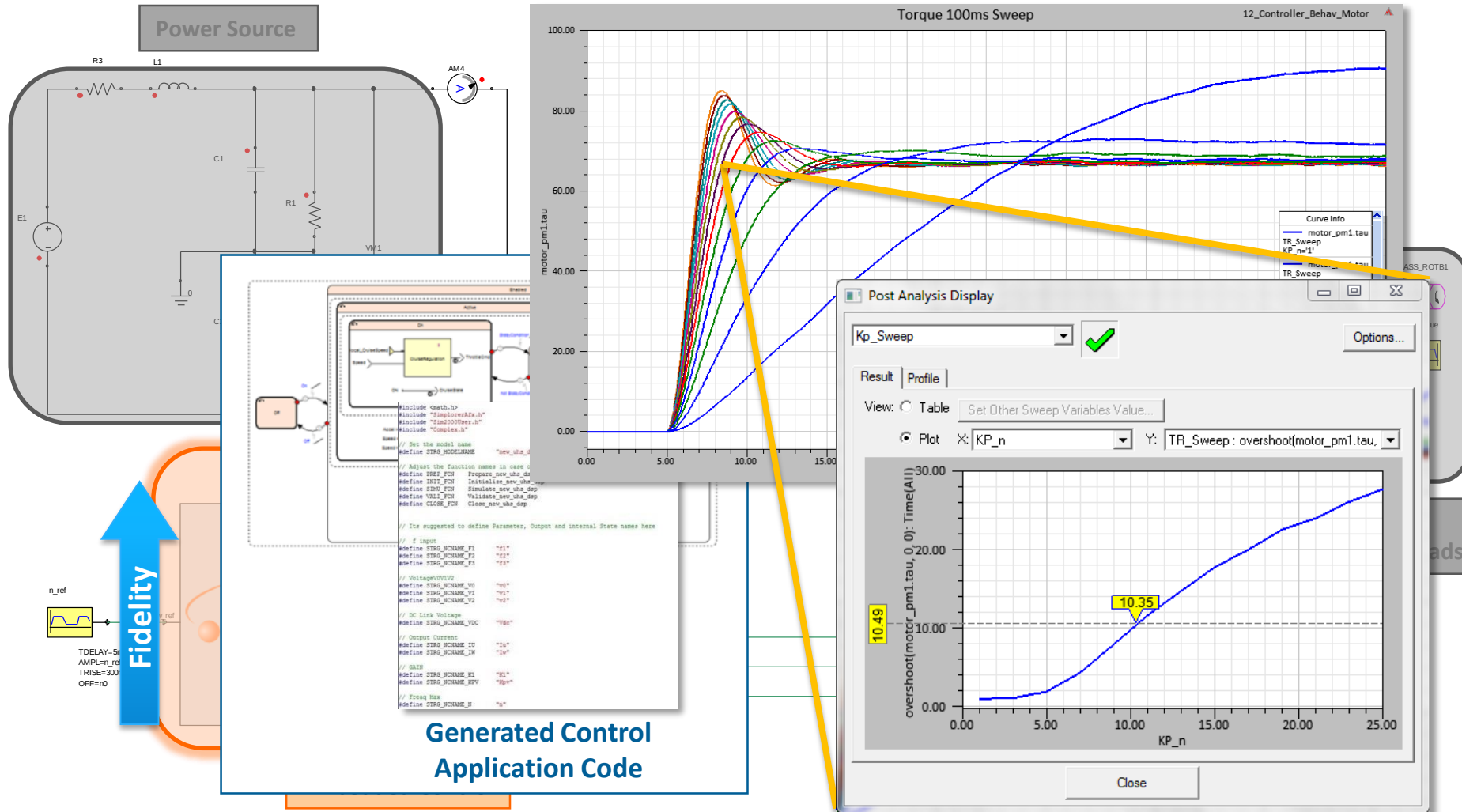


## Goal: EMC Prediction



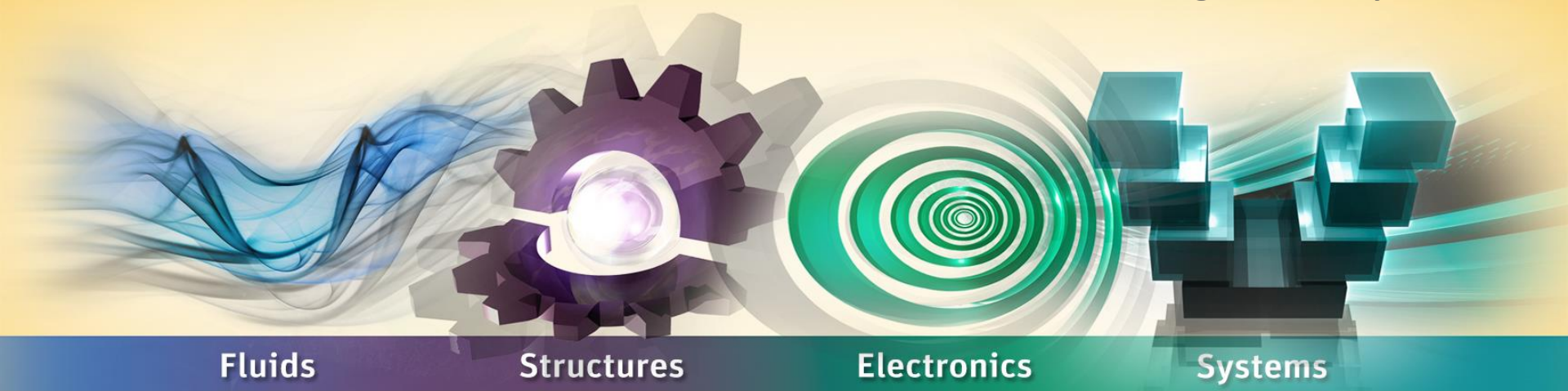
# Assembling & Analyzing the System

Goal: MiL, SiL Testing / Calibration & Tuning



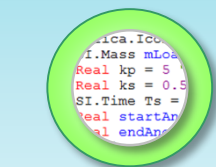
# Simplorer for Systems

*Modeling & Analysis*

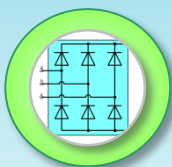


# Modeling the System

*Powerful Capabilities for Assembly and Reuse*



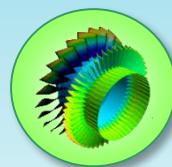
**Language-Based  
Modeling**



**Multi-Domain Model  
Libraries**



**Co-simulation  
with 3D Physics**



**Reduced Order  
Model Creation**



**Embedded Software  
Integration**



**Functional Mockup  
Interface (FMI)**



**VHDL-AMS  
C/C++  
SPICE  
SML  
Modelica**



Multi-Domain

Analog

Digital

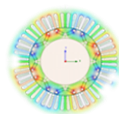
Power Systems

Manufacturers

App-Specific



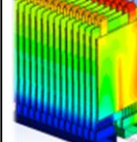
**ANSYS 3D Physics**



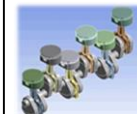
EM



Fluid



Thermal



Mech



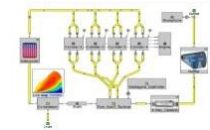
**ANSYS SCADE**



**Simulink  
C Code**



**3rd Party System  
Modeling tools**  
(AMESim, Simulink,  
Dymola, GT Suite etc.)



# Analyzing the System

*Robust Support for Simulation-Based Testing*



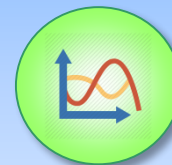
**Robust, High-Performing Solvers**



**Simulation Synchronizer**



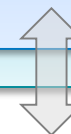
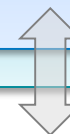
**Basic Analysis, Sophisticated Tests**



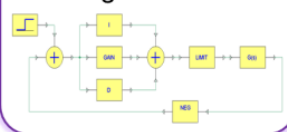
**Waveform & Data Post-Processing**



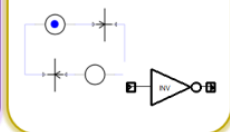
**Reporting, Scripting & Automation**



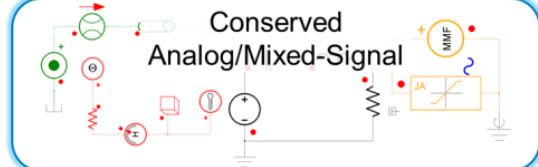
**Signal Flow**



**Discrete Event**



**Conserved Analog/Mixed-Signal**



**Frequency-Domain**

**Time-Domain**

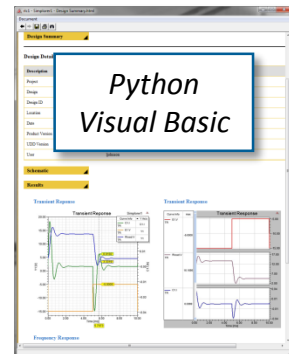
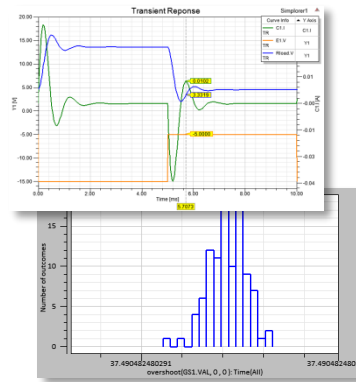
Parameter Sweeps

Statistical

Sensitivity

Worst-Case

Optimization

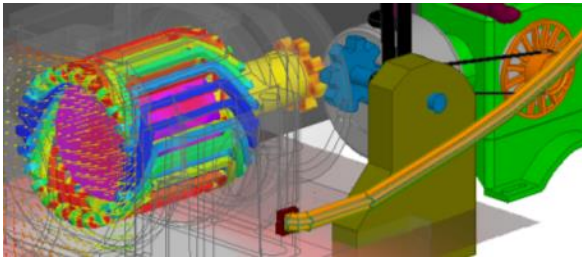
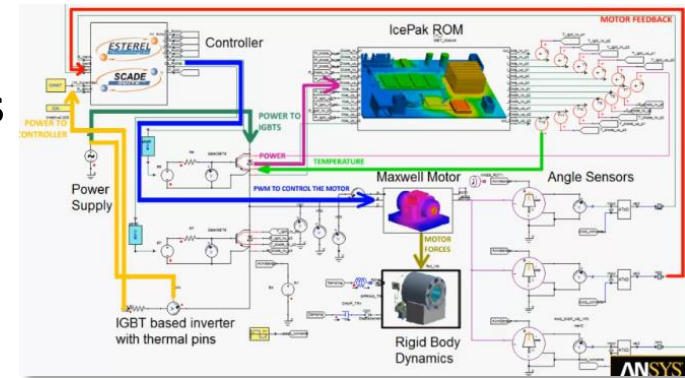


**A Comprehensive platform for modeling, simulating, and analyzing virtual system prototypes**

*Spans electrical, electronics, mechanics, thermo-fluids, and embedded software systems*

## Open Integration of existing tools

*Full FMI compliance enables embracing and extending existing tools and libraries (Modelica and other FMI-compliant tools)*

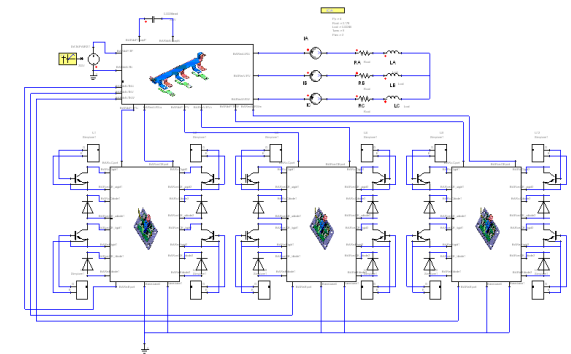


## 3-D Precision When You Need It

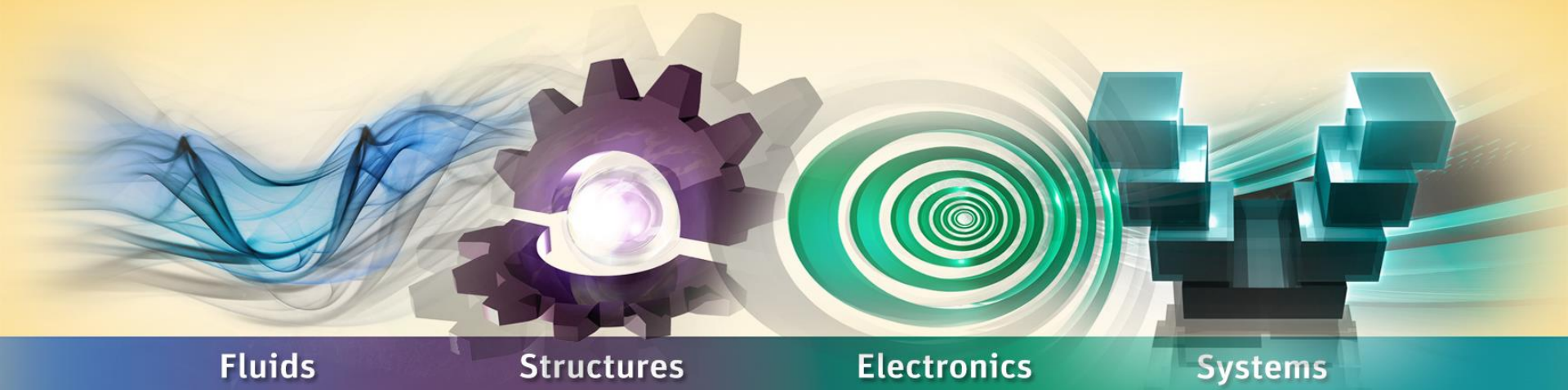
*Cosimulation with 3-D solvers and reduced-order modeling (ROM) captures complex multi-physics interactions when precise system verification is required*

## Leader in simulation for power electronics and electrical systems

*Rich modeling libraries and design automation designed especially for high-performance power electronics and electromechanical simulation*



# Thank You!



Fluids

Structures

Electronics

Systems

**Lee Johnson**

Product Manager

System Modeling & Simulation

[lee.johnson@ansys.com](mailto:lee.johnson@ansys.com)